

RECOVERY OF WATER FROM BOILER FLUE GAS

**QUARTERLY REPORT FOR THE PERIOD
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by

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EXECUTIVE SUMMARY

Background

This project is developing new designs for condensing heat exchangers to recover water vapor from flue gas at coal-fired power plants. Pilot scale heat transfer experiments performed using boiler flue gas will determine the extent to which the condensation processes for water and acid vapors can be made to occur separately in different heat transfer sections. Both smooth wall tube and fin-tube heat transfer bundle designs for condensation of water vapor will be developed and tested. Boiler and turbine cycle analyses will be performed to determine potential heat rate gains from recovering sensible and latent heat from flue gas.

Results

The majority of the effort this past quarter involved an iterative process of contacting potential fabricators of the smooth-wall tube test apparatus and then modifying and refining the design to improve functionality and reduce costs. The design of the test apparatus is now complete. Fabricators and vendors have been selected for the components and purchase orders have been issued. The instrumentation has been selected and purchase orders have been issued for these items, as well.

Design analyses were also carried out on fin-tube heat exchangers for the low temperature heat transfer sections. These analyses were based on heat transfer theory for annular fins on circular tubes. A preliminary selection has been made of the desired fin geometry and potential fin-tube vendors have been identified. The fin-tube bundle design will be finalized over the coming months, a vendor will be selected, and a purchase order will be issued.

Based on estimates of the delivery times for the various components given to us by the vendors, we are hopeful we will be able to assemble the test apparatus, connect it to the boiler and begin testing by the end of September 2006.

PROJECT DESCRIPTION

Background

As the U.S. population grows and demand for electricity and water increase, power plants located in some parts of the country will find it increasingly difficult to obtain the large quantities of water needed to maintain operations. Most of the water used in a thermoelectric power plant is used for cooling, and DOE has begun to focus on possible techniques to reduce the amount of fresh water needed for cooling. DOE is also placing emphasis on recovery of usable water from sources not generally considered, such as mine water, water produced from oil and gas extraction, and water contained in boiler flue gas. This project is developing designs for condensing heat exchangers for power plant applications and is evaluating the heat rate and emissions co-benefits of installing these at coal-fired power plants to recover water from flue gas.

The moisture in boiler flue gas comes from three sources ... fuel moisture, water vapor formed from the oxidation of fuel hydrogen, and water vapor carried into the boiler with the combustion air. The amounts of H₂O vapor in flue gas depend heavily on coal rank. Calculation of typical coal flow rates and flue gas moisture flow rates for 600 MW pulverized coal power plants show that flue gas moisture flow rates range from nearly 200,000 to more than 600,000 lbs/hr of water. In contrast, typical cooling tower water evaporation rates for a 600 MW unit are 1.6 million lbs/hr. Thus, Powder River Basin (PRB) and lignite power plants, equipped with a means of extracting all the flue gas moisture and using it for cooling tower makeup, would be able to supply from 25% (for PRB) to 37% (for lignite) of the makeup water by this approach.

Flue gas from coal-fired boilers contains concentrations of sulfuric acid (H₂SO₄) ranging up to 50 ppm with acid dewpoints in the 230 to 300°F range.

Stack emissions of H_2SO_4 from coal-fired boilers has recently emerged as a serious problem, particularly for some boilers equipped with SCR reactors for NO_x control. A side benefit of cooling the gas to remove H_2O is simultaneous removal of the vapor phase $\text{SO}_3/\text{H}_2\text{SO}_4$. Other acidic compounds such as nitric acid (HNO_3) and hydrochloric acid (HCl) will also be removed.

There can also be boiler efficiency and heat rate benefits from cooling the flue gas to dry it. If the rejected sensible and latent heat can be put to good use in the boiler or turbine cycle, this will result in an increase in boiler efficiency and a decrease in net unit heat rate. For example, the efficiency of a well designed boiler firing a bituminous coal would increase from 89 to approximately 96% if the gas temperature were reduced to a level sufficient to condense about one half of the flue gas moisture. In addition, the reduced stack gas flow rate would result in a smaller power requirement for the induced draft fans. Some of these gains would be balanced out by the increase in gas side pressure drop due to the moisture removal equipment.

Objectives

This project is developing new designs for condensing heat exchangers to recover water vapor from flue gas at coal-fired power plants. Pilot scale heat transfer experiments performed using boiler flue gas will determine the extent to which the condensation processes for water and acid vapors can be made to occur separately in different heat transfer sections. Both smooth wall tube and compact fin-tube heat transfer bundle designs for condensation of water vapor will be developed and tested. Boiler and turbine cycle analyses will be performed to determine potential heat rate gains from recovering sensible and latent heat from flue gas.

The project is a combination of laboratory and pilot scale experiments and computer simulations. Computer analyses will be carried out to design a fin-tube

heat exchanger to condense water vapor from flue gas in an efficient manner. Laboratory and pilot plant experiments will be conducted to determine the extent to which removal of acid from flue gas and condensation of H₂O vapor can be achieved in separate stages of the heat exchanger system and additional experiments will be carried out to measure the heat transfer effectiveness of the fin-tube bundle designed for condensation of water vapor. Analyses of the boiler and turbine cycle will be carried out to estimate potential reductions in heat rate due to recovering sensible and latent heat from the flue gas.

RESULTS OF WORK DURING REPORTING PERIOD

Approach

The majority of the effort this quarter involved an iterative process of contacting potential fabricators of the smooth-wall tube test apparatus and then modifying and refining the design to improve functionality and reduce costs. Design analyses were also carried out on fin-tube heat exchangers for the low temperature heat transfer sections. These analyses were based on heat transfer theory for circular tubes with annular fins.

Results and Discussion

Smooth Wall Tube Bundle Apparatus. The designs have been finalized for the various smooth-wall tube bundle test section components and purchase orders have been issued. Some components will be custom-fabricated (for example, heat exchangers and ductwork) while others are standard catalog items (for example, water heater, flow meters, thermocouples, and exhaust fan). Delivery estimates from vendors indicate the various components will be delivered in July and August. Based on those estimates, test section assembly is planned for August/September, with testing beginning in mid to late September.

The parameters to be measured include gas and water flow rates; water, gas and tube wall temperatures; flue gas moisture condensation rate; vapor phase concentrations of H_2O , H_2SO_4 and HCl ; and sulfate, chloride and nitrate concentrations in the H_2O condensate. Table 1 summarizes the instrumentation and measurement methods which will be used for the various parameters.

Table 1
Instrumentation

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|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none">• Flue Gas Flow Rate (S-Probe Traverses)• Cooling Water Flow Rates (Rotometers)• Water and Flue Gas Inlet and Outlet Temperatures (Thermocouples)• Tube Wall Temperatures (Thermocouples)• Moisture Condensation Rate (Bucket, Stopwatch and Scale)• H_2SO_4 and HCl Gas-Phase Concentrations (Controlled Condensation Method) |
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Fin Tube Heat Exchange Bundles. The design of the fin-tube heat exchange bundles has involved two main tasks:

- identification of vendors with capabilities to manufacture annular fin assemblies made from stainless steel;
- use of fin design calculations to determine the fin geometry which will maximize heat transfer and minimize costs.

As a result of this process, we have tentatively selected 0.250" high by 0.015 thick annular stainless steel fins arranged 12 to the inch on 0.50" OD tubes. We are now in the process of obtaining quotes from fin-tube fabricators and refining the design of the fin-tube bundle.

Conclusions

The design of the test apparatus with smooth-wall tube bundles is complete. Fabricators and vendors have been selected for the components and purchase orders have been issued. The instrumentation has been selected and purchase orders have been issued for these items, as well.

The design and analysis of a fin-tube bundle for one of the low temperature heat exchangers is in progress. A preliminary selection has been made of the desired fin geometry and potential fin-tube vendors have been identified. The fin-tube bundle design will be finalized over the coming months, a vendor will be selected, and a purchase order will be issued.

Based on estimates of the delivery times for the various components given to us by the vendors, we are hopeful we will be able to assemble the test apparatus, connect it to the boiler and begin testing by the end of September 2006.

COST STATUS

COST PLAN/STATUS

Baseline Reporting Quarter	YR 1 Start: 1/1/06 End: 12/31/06				YR 2 Start: 1/1/07 End: 12/31/07				YR 3 Start: 1/1/08 End: 6/30/08	
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
<u>Baseline Cost Plan</u> (from SF-424A)	(From 242A, Sect. D)				(From 242A, Sect. D)					
Federal Share	\$55,273	\$55,273	\$55,273	\$55,273						
Non-Federal Share	\$14,905	\$14,905	\$14,905	\$14,905						
Total Planned (Federal and Non-Federal)	\$70,178	\$70,178	\$70,178	\$70,178						
Cumulative Baseline Cost	\$70,178	\$140,356	\$210,534	\$280,711						
<u>Actual Incurred Costs</u>										
Federal Share	\$1,711	\$13,166								
Non-Federal Share	\$12,107	\$8,071								
Total Incurred Costs-Quarterly (Federal and Non-Federal)	\$13,818	\$21,237								
Cumulative Incurred Costs	\$13,818	\$35,055								
Variance										
Federal Share	(\$53,562)	(\$42,107)								
Non-Federal Share	(\$2,798)	(\$6,834)								
Total Variance-Quarterly (Federal and non-Federal)	(\$56,360)	(\$48,941)								
Cumulative Variance	(\$56,360)	(\$105,301)								

MILESTONE PLAN AND STATUS

The Milestones identified below serve as the baseline for tracking performance of the project.

- FY06 Q2: Initiate design of the smooth tube test apparatus.
- FY06 Q3: Perform analyses in order to design fin-tube bundle.
- FY06 Q4: Begin fabrication of the fin-tube bundle.
- FY07 Q1: Perform smooth tube tests at Lehigh's oil-fired boiler.
- FY07 Q2: Perform fin-tube array tests at Lehigh's oil-fired boiler.
- FY07 Q3: Analyze oil-fired boiler test data and attempt to determine effects of flue gas composition and temperature on water condensation.
- FY07 Q4: Set-up and run first round of tests at pilot scale coal-fired boiler.
- FY08 Q1: Run remaining tests with fin-tube array at pilot scale coal-fired boiler.
- FY08 Q2: Perform heat rate analyses to estimate potential reductions in heat rate due to recovering heat from flue gas.
- FY08 Q3: Begin project final report preparation.

Status

The design of the smooth wall tube test apparatus has been completed and purchase orders have been issued for the various components. Based on estimates of the delivery times for the various components given to us by the vendors, we are hopeful we will be able to assemble the test apparatus, connect it to the boiler and begin testing by the end of September 2006. The design analyses of a fin-tube bundle for the low temperature heat exchanger section are underway. The design will be finalized over the coming months, a vendor will be selected and a purchase order will be issued for fabrication.

SIGNIFICANT ACCOMPLISHMENTS.....None in FY06 Q3

PROBLEMS/DELAYS.....None in FY06 Q3

PRODUCTS PRODUCED/TECHNOLOGY TRANSFER ACTIVITIES.....None in
FY06 Q3